DESIGN OF A PULSED-CURRENT SOURCE FOR THE INJECTION-KICKER MAGNET AT THE LOS ALAMOS NEUTRON SCATTERING CENTER

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ABSTRACT

This paper describes the design and performance of a pulsed-current source for the Proton-Storage-Ring (PSR) injection-kicker magnet at the Los Alamos Neutron Scattering Center (LANSCE). To deflect beam into the PSR injection-transport line, the pulsed-current source provides a current pulse with a flat-top amplitude that can be varied from 180 A to 225 A with a width of up to 1.4 ms, at repetition rates ranging from 0 to 40 Hz, and with pulse current regulation < ± 0.5%.

INTRODUCTION

The purpose of the pulsed-power source is to provide a controlled-current pulse to the PSR Ring-Injection-KIcker (RIKI) magnet which can then deflect the particle beam and send it to the PSR. In order to deflect beam into the PSR injection-transport line, the pulsed-current source provides a current pulse with a flat-top amplitude than can be varied from 180 A to 225 A with a width up to 1.4 ms. Figure 1 is a simplified block diagram of the pulsed-current source. The main pulsed-power components are the pulse

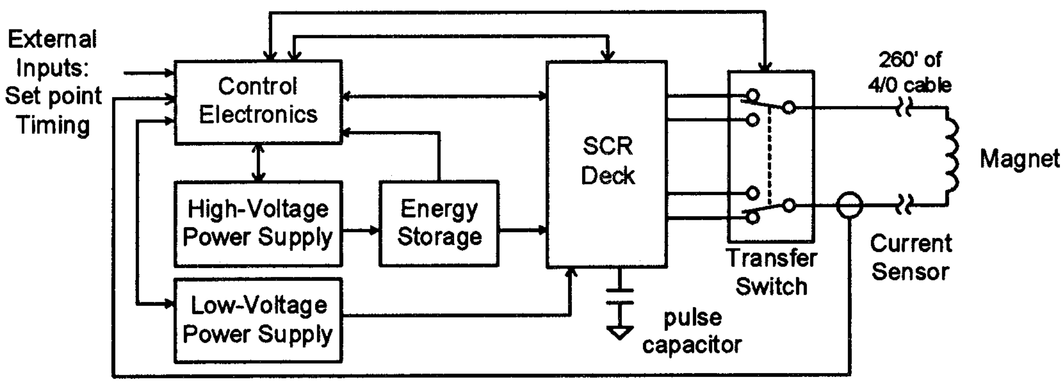

Fig. 1. Simplified block diagram of the pulsed-current source for the Los Alamos Proton-Storage-Ring (PSR) kicker magnet.

capacitor, SCR deck, transfer switch, and the magnet. The pulse capacitor is actually two 1-kV 1000-μF capacitors connected in parallel. The SCR deck consists primarily of the SCRs used to perform the switching function and the pulse-capacitor voltage-regulator circuitry. The transfer switch, which is controlled from the Control Electronics, is configured according to the operating mode. Ancillary components in the system, shown in Fig. 1, include the energy-storage, low-voltage power supply and the high-voltage power supply. The energy storage is an 18,000-μF capacitor bank used to provide a low-impedance source for the pulse-capacitor voltage regulator on the SCR deck. The high-voltage supply is a

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This paper describes the design and performance of a pulsed-current source for the ProtonStorage- Ring (PSR) injection-kicker magnet at the Los Alamos Neutron Scattering Center (LANSCE). To deflect beam into the PSR injection-transport line, the pulsed-current source provides a current pulse with a flat-top amplitude that can be varied from 180 A to 225 A with a width ofup to 1.4 ms, at repetition rates ranging from 0 to 40Hz, and with pulse current regulation<± 0.5%.

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Sorenson model 600-8T unit, rated for 600 V at 8 A. The low-voltage power supply is an EMI 20T500. The Control Electronics, which provides monitoring and control of the pulsed-current source, can command the source to operate in DC Mode (where the low-voltage power supply is programmed as a current source), or in Pulse Mode (providing current pulses). This paper focuses on the design and operation of the source in Pulse Mode.

PULSED-POWER DESIGN

When commanded to Pulse Mode, the transfer switch shown in Fig. 2 is set to position "A." The SCR deck, which consists of the switching SCRs and a pulse-capacitor voltage regulator, can then switch the pulse capacitor and low-voltage power supply in and out of the magnet circuit. The output-current waveform during operation in Pulse Mode can be divided into three portions: *charge*, *freewheel*, and *recovery*. The following sections describe the circuit operation of Fig. 2 for each of these three portions of the pulse cycle.

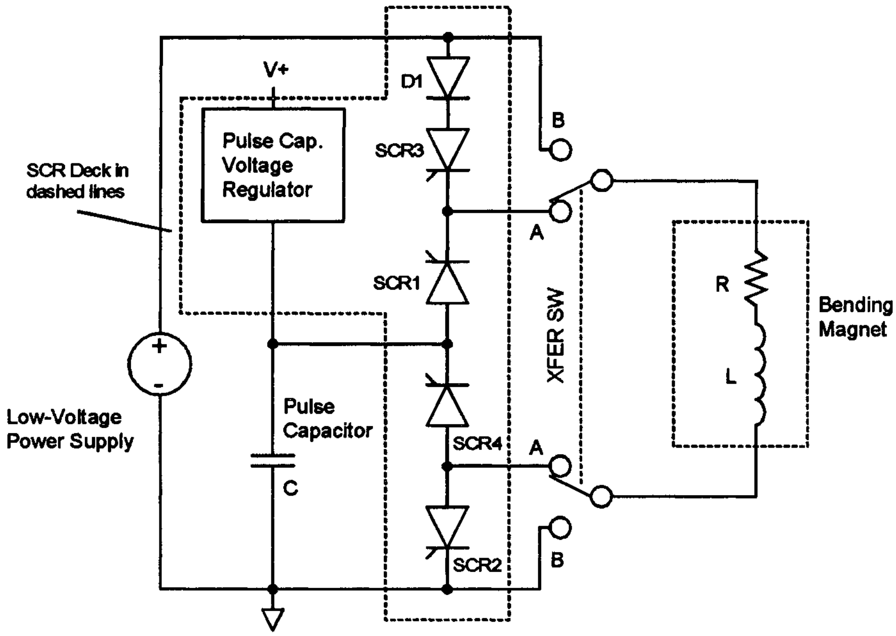

Fig. 2. Schematic diagram of the Pulse Mode configuration. The SCRs on the SCR deck are fired at precise time intervals to connect and disconnect the pulse capacitor and the low-voltage power supply with the magnet.

Charge Portion

When the pulsed-current source receives a valid trigger, the Control Electronics first fires SCRs 1 and 2 which connect the pulse capacitor to the magnet. If the capacitor has an initial voltage, the current in the magnet then rises according to

$$i_{magnet} = \frac{(v_{ci} - v_d)}{L\omega_o} e^{\frac{-R}{2L}t} \sin[\omega_o t] \quad (1)$$

with

$$\omega_o = \sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2} \quad (2)$$

where L is the circuit inductance, C is the circuit capacitance, R represents the total resistive losses, ω_o is the resonant frequency of the circuit, v_{ci} is the initial pulse capacitor voltage, and v_d is the total voltage

drop of the semiconductors. If both the total voltage drop of the semiconductors and the circuit resistance are neglected, equations 1 and 2 reduce to the first-order form:

$$i_{magnet} = v_{ci}\sqrt{\frac{C}{L}}\sin(\omega_o t) \tag{3}$$

and

$$\omega_o = \frac{1}{\sqrt{LC}} \tag{4}$$

which are much easier to use in calculating magnet current. By using equations 3 and 4, an error of less than a few percent is introduced into the calculations. Since the error is small, and the first-order equations are easier to use, the magnet and capacitor voltage can be described by

$$v_c = v_{ci}\cos(\omega_o t), \tag{5}$$

where v_c is the instantaneous pulse capacitor voltage. The objective of the *charge* portion of the cycle is to build up current in the magnet so it can then go into *freewheel* or the "flat-top" portion of the cycle. Thus, after a predetermined time delay, SCR3 is fired to initiate the *freewheel* portion of the cycle. Using fixed values of L = 7.3 mH, C = 2000 μF, t_{delay} = 6.75 ms and a required magnet current flat-top of

i_{mag} = 225 A,

the required pulse-capacitor initial voltage is

$v_{ci} \cong 440$ V.

Thus, all the variables are fixed as shown above, and the pulse-capacitor voltage regulator controls the initial voltage on the pulse capacitor, and sets the voltage in accordance with the programmed output-current level. The circuit of Fig. 2 was modeled in SPICE[1] (including models of the SCRs) using values listed above to produce the waveforms shown in Fig. 3 of typical output pulses. Note that just after the current peak (when the pulse capacitor voltage is negative), SCR3 is fired, initiating the *freewheel* portion of the cycle.

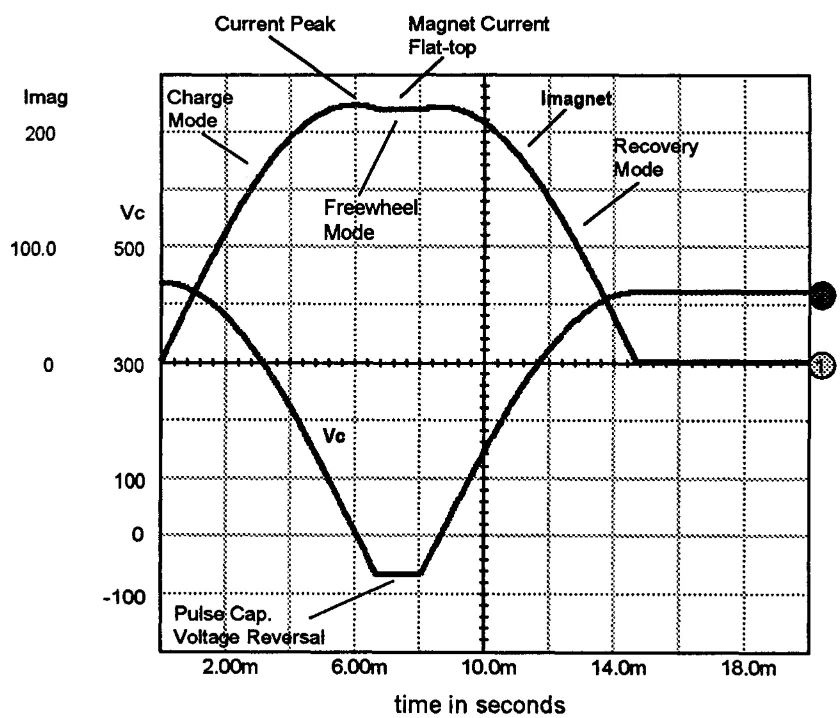

Fig. 3. SPICE-modeled waveforms for magnet current and capacitor voltage during a typical pulse. Trace 1 is the magnet current at 50 A/div., and Trace 2 is the pulse-capacitor voltage at 100 V/div.

Freewheel Portion
During the *freewheel* portion of the cycle, the low-voltage power supply is connected to the magnet via SCR3 and D1 and is used to maintain the flat-top current. The output voltage of the supply is set to compensate for the IR losses in the circuit (shown by R in Fig. 2) and negates the L/R time constant effect of the circuit. This mode may last indefinitely if properly configured, but is typically set for about 1 ms. After this time, SCR4 is triggered which initiates the *recovery* portion of the cycle.

Recovery Portion
In this portion of the cycle, SCR4 fires and turns off SCR1 which causes the magnet current to flow into the pulse capacitor in sinusoidal fashion. The current continues to flow into the pulse capacitor until it starts to reverse polarity in SCR4 and SCR3 causing them to turn off. The voltage at the pulse capacitor will not return to its initial value because of circuit losses; thus the pulse-capacitor voltage regulator turns on, charging the capacitor to the proper voltage and preparing it for the next pulse.

The SCRs used in the system are IRKHF180-10DL inverter-grade modules, rated at 1000 V, 180 A, with turn off times of less than 15 μs. Each module also has an internal diode that can be connected for external use. Four of these modules are mounted on a forced-air-cooled heatsink and are calculated to dissipate about 60 W of power each at the maximum repetition rate of 40 Hz. The heatsink operates at less than the 150°F thermal-interlock limit giving sufficient margin for the operating junction temperature of each device. As shown in Fig. 2, only one internal diode, that of SCR module 3, is used in the system to provide added protection to the low-voltage power supply.

RESULTS

The pulsed-current source has been operated with a repetition rate of up to 49 Hz. Operation above this rate is presently limited by the pulse-capacitor voltage-regulator recharge time. The pulsed-current source was designed (and all the components rated) for 60-Hz operation which is close to the maximum theoretical repetition rate of the system based on the resonant frequency of the magnet and pulse capacitor. Figure 4 shows typical pulses for both the magnet-current output and the pulse-capacitor voltage. At present, an internal repetition-rate limiter circuit has the system set for a maximum of 40 Hz. Trace 1 of Fig. 4 is

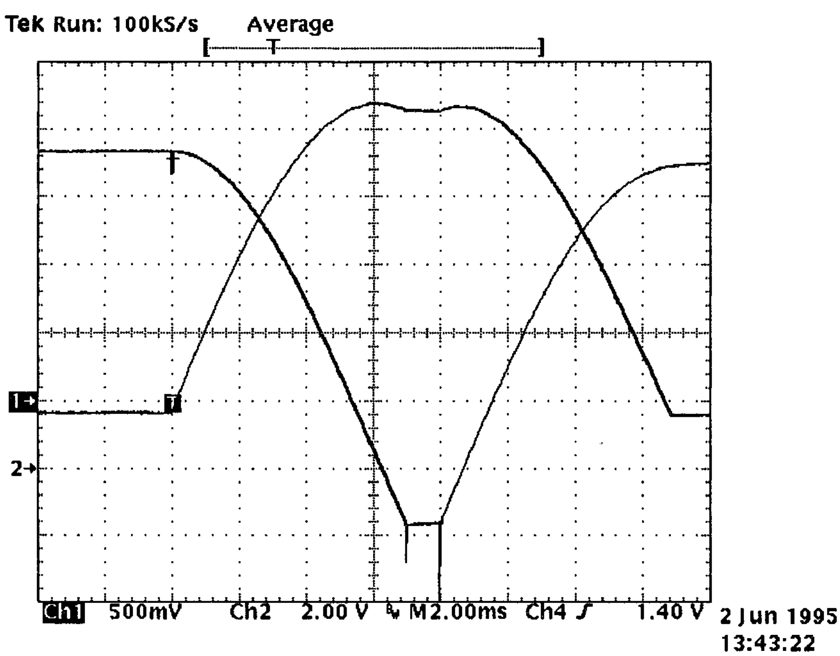

Fig. 4. Actual waveforms of the magnet current and the pulse-capacitor voltage during a typical pulse. Trace 1 is the magnet current with a sensitivity of 100 A/V, and trace 2 is the pulse-capacitor voltage with a sensitivity of 50 V/V.

the magnet-current waveform. Its sensitivity is 100 A/V, and Trace 2 is the pulse-capacitor voltage using a sensitivity of 50 V/V. The waveforms have been averaged to reduce instrumentation noise and provide greater detail in viewing. The "flatness" of the flat-top was measured and found to vary less than ± 0.5%.

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